BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Selected Comments on Agena and Titan III Family Stages
Case 720

DATE: March 26, 1968

FROM: C. Bendersky

ABSTRACT

This memo presents (unclassified) comments on the status of Lockheed Agena and Titan III family propulsion stages gathered to support current NASA Orbital Workshop Studies.

(NASA-CR-95511) SELECTED COMMENTS ON AGENA AND TITAN 3 FAMILY STAGES (Bellcomm, Inc.) 23 p

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MEMORANDUM FOR FILE

This memo presents (unclassified) comments on the status of both the Lockheed Agena Space Propulsion Systems and the Martin Titan III booster family. The data presented were primarily obtained during a visit to Lockheed, Sunnyvale, California, January 23 and Martin, Denver, Colorado, January 24-25, 1968[1]. H. S. London was present at Martin. This memo will discuss specific operational features of the subject stages of current interest to the Workshop B & C study. The detailed characteristics of the stages and flight performance data are available upon request from this writer. This memo reports information available as of February 1, 1968 and will be updated as warranted.

1.0 AGENA STAGES

It must be emphasized that the available Agena has achieved a high degree of reliability through flights on Thor, Atlas and Titan boosters. For example, more than 10 Titan IIIB/ Agenas have been successfully flown from the Western Test Range (WTR).

The existing Agena (SSOIB or Agena D) is 5 ft. in diameter, weighs approximately 15,000 lbs and uses Acid/UDMH propellant. Presently under development is an advanced Agena using the Apollo propellants (N_2O_4/50-50). As conceived, the Agena (Figure 1) is a core stage to which mission peculiar equipment is attached. Off the shelf "peculiars" include two versions of secondary propulsion systems (SPS) (Figure 2 and 3), cold gas attitude control kits, various battery and power options, as well as communication options. The Agena has been used as a stable platform providing power and commands to many varied types of payloads--maximum injected payloads have exceeded 8000 lbs. The present Agena engine system using the Bell Aerosystem 8247 engine can restart at least 15 times in space. No auxiliary propellant settling devices are required. In the multi-restart configuration

[1]An Air Force sponsored symposium on the Titan III family of configurations and capabilities was presented to a large industry audience on January 25. Topics of the presentations may be reviewed by contacting this writer.

the pumpfed engines are started using pressurized start tanks. The tanks are recharged with propellants during main stage operation. Approximately 0.7 seconds of main stage are required. The minimum impulse bit ($\approx$12,000 lbs-sec) requires a total of 80-lbs of propellants of which 50-lbs are impulse propellants and 30-lbs are additional oxidizer to prime the chamber during startup and cool-down the chamber during shut-down. This minimum impulse bit is of the same order of time as the start tank recharge time. The propellant utilization can be very high as the last propellant (trapped in the screens, sumps and lines) are sufficient for a final (safe) burn. The advanced (improved) Agena is in reality a new stage using Apollo propellants (rather than Acid/UDMH) having a higher performing (new) Bell engine. Advanced types of SPS are planned as well as a "Shell 402" type of hydrazine ACS system. Availability is presently planned for 1970 (Figure 4). Rumors have persisted that the advanced Agena may be cancelled. Lockheed denies this emphatically; rather Lockheed states that the program "may" be reconstructed to eliminate advanced types of subsystems. The availability of the advanced Agena while desirable, is not necessary for contemplated use in orbital support missions.

1.1 Agena Costs

Lockheed states that they have present complete responsibility for sale and servicing of Agena stages. Lockheed responsibility includes payload integration down-to and including the shroud (fairing) installation on the Titan core (IIIB) and all smaller capacity launch vehicles. For use on larger Titans, Lockheed has designed (and mocked up) a 10 foot diameter "full-length" load carrying adapter[2] (Figure 5) which completely shrouds the 5 ft. diameter Agena. This adapter will be installed underneath the selected Titan fairing (e.g., the 10 ft. dia. x 50 ft. long Titan IIIC fairing now under development by McDonnell Douglas). A typical Agena cost breakdown is as follows:

Agena Bird	$1.1 (including full-barrel adapter)
Software & Mission Peculiar	1.5
Launch Costs	0.7
	$3.3 Million per Bird *

[2]Also called full-barrel adapter.

*Costs provided by Lockheed.

The external fairings are GFE and are estimated to cost about $100,000.

It is noteworthy that Lockheed would expect to employ between 165-to-300 people at the Eastern Test Range (ETR) for launch support.

1.2 Rendezvous Capability

It is this writer's considered opinion that an Agena can easily be made into an active rendezvous stage with translation and soft docking capability by proper addition of SPS & ACS modules and state of the art GNC equipment. In fact, a stage having almost this capability is presently undergoing qualification at Lockheed in their anechoic chamber (details classified).

1.3 Space Storeability

Agena presently is required to be propulsively deorbited at mission completion. This last firing has been routinely accomplished after orbital durations in excess of 3 months. No restart problems are anticipated in mission times over a year, although Lockheed does recommend a thorough reexamination of engine components (i.e., seals).

1.4 Availability

Lockheed stated that the first Agena (in a production group for NASA purposes) can be available 18-to-20 months after go-ahead. Each succeeding bird would require 13 months; less time if mission peculiar subsystems become standardized.

1.5 Atlas Agenas

The Convair Atlas buy will be completed (delivered) by August. Flights are (presumed) scheduled up to 1970. These birds can possibly be retro-fitted with Agenas and flown out of both ETR & WTR. (NASA has approved Atlas Centaur flights scheduled up to 1972).

1.6 Facilities

Figure 6 presents the Agena launch facility status. WTR can presently handle Thorad, Atlas and Titan IIIB systems. Only Atlas Agena's can presently be flown from ETR. As shown in Figure 6 the projected capabilities from both WTR & ETR are large. The estimated costs of providing Titan IIIB/Agena capability at ETR is of the order of $10 million. Lockheed reported (on January 31) that they were "90 percent" sure that such a facility would be available to support COMSAT as well as Air Force needs. In this event the facility could be of value particularly for use with the TALL[2] concept of direct unmanned logistic supply in support of Augmented LM lunar surface exploration.

2.0 TITAN III

The Titan III presentation had the aura of prescience and solid accomplishments complete with Air Force blessing in the presence of Colonel F. W. Kniss of the Titan III System Program Office. The briefing (classified) was rather complete. Copies of the charts are available from the writer. The presently approved Titan III configurations are shown in Figure 7. A Martin provided Titan III cost summary is presented as Table 1. The costs are not NASA approved. A description of the vehicles follow:

Titan IIIA - No longer in production, therefore not described;

Titan IIIB - The two stage liquid core. Contains a BTL radio guidance. The Titan IIIB birds have been flown with Agena upper stages as described in section 1.0;

Titan IIIC - Basically the "B" core with two strapon 5-segment 120-inch diameter solid rocket motors (SRM) fired as a zero stage, plus a transtage. Guidance is the AC Electronic inertial guidance system. The Titan IIIC has flown 9 times from the WTR. Figure 8 contains payload descriptions and flight results of the last five missions;

Titan IIID - Essentially a Titan IIIC without a transtage. Radio guidance is used. Missions are classified;

Titan IIIM - The "B" core has a lengthened first stage; new man-rated higher performance engines in both core stages and 7-segment 120-inch diameter SRM. The bird is designed to inject the MOL directly into circular orbit and therefore has no transtage. (The second stage cannot restart. For coast type trajectories as used in altitude changes, the Transtage could be added or possibly the Agena).

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[2]TALL = Titan/Agena Logistics Lander

The Titan IIIM has man-rating redundancy in critical areas. The AC Electronics inertial guidance system is used with the Gemini launch vehicle inertial guidance as backup.

2.1 Production Rates and Availability

Throughout the whole Titan family "commonality" is the key word. Except for Titan IIIM, the core vehicles are essentially identical with the exception of mission peculiars such as guidance. According to Martin, Figure 9 presents the Air Force Titan III acceptance schedule for the 1968-1971 time period. The total for all birds is 51. Breakdown of the total in actual types of Titan III's is classified "secret" and therefore omitted. By 1970, Martin expects the Titan III family production rate to be 18 vehicles per year. Under present ground rules, Martin stated that a Titan bird for use by NASA, built from scratch, could be made available within 24 months--if pulled from a production line, the availability could be improved to 13 weeks from order. Subsequent conversations with Martin revealed that the 1970 production rate represents half the plant and tooling capacity. However, this extra tooling is mothballed. The same conditions exist with all major subcontractors (e.g., Aerojet General). It is not known at this time the required lead time and costs for an increased production rate.

2.2 Transtage

The Transtage as existing (Figure 10) is a 10-ft. diameter by 15 ft. long liquid propellant propulsion system weighing 27,550 lbs and is used as a third (liquid) stage in the Titan IIIC launch vehicle. The Transtage is composed of an aft propulsion module and a forward control module. The propulsion module contains two 8000 lbs thrust Aerojet pressure fed ablative engines as main propulsion. The control module contains all the electronic systems and the attitude control system (ACS). Hydraulic power is provided by an electrically driven pump. The present life of the Transtage is approximately 6-hours due primarily to power limitations. A capability for up to 24-hours is now under development.

The Transtage was orginally programmed for use in the (manned) Dynasoar program and was therefore to be man-rated for Air Force use. Complete man-rating was not accomplished. However, man-rated design safety factors (1.4) were specified and the main propulsion systems were developed under "man-rating criteria" and are dynamically stable. A further step to man-rating reliability will be the use (Vehicle 17) of a new mono-propellant hydrazine ACS. The system has a capacity of 60,000 lbs-sec of impulse and contains 6 engine modules. Each module has complete redundancy, i.e., two thruster malfunctions are required before module failure. Various upratings of the Transtage have been studied by Martin; the most near-term would replace the two Aerojet 8000-lbs thrust engines by a single 8533 Bell Aerosystems engine now under development for advanced Agenas. An 8533 engine transtage would increase payloads of the Titan IIIC to synchronous equatorial orbits by over 50%: however, the 8533 engine would not have the "man-rated design features" of the present engines.

Martin indicated they would examine the capability of the Transtage to be modified for use as a unmanned logistic system. The data were provided to H. S. London[4]. According to Martin, the preliminary cost estimate was (not exceeding) $\$18 \times 10^6$ non-recurring.

2.3 Man-Rating Philosophy

To this writer the subject of man-rating is as confusing as the clearest of Kafke. Of all the Titan III vehicles, only the IIIM vehicle is programmed for man-rating. "The design philosophy followed throught the Titan IIIM---that there be no aborts because of the a single failure---requried the use of redundant equipment in critical areas". Thus the instrumentation system is completely redundant. The IIIM guidance and control system has a prime (BIGS)[5] and a backup (GIGS)[6]. Fast malfunctions result in automatic switchover from BIGS to GIGS. Slow malfunctions are detected by monitored tracking data on the ground and by airborne displays monitored by the crew. Switchover is initiated by the flight crew. The malfunctioning system is identified by comparison of each system with a third reference system comprised of accelerometers and reference gyros. Flight control sensor and computer redundancy is provided by majority voted elements.

The Titan IIIM thrust vector control systems have completely redundant hydraulics and power supplies in the SRM zero stage, have primary and secondary hydraulics on the first liquid stage and no hydraulic backup in the second liquid stage. The latter is reconciled based on past testing experience.

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[4] Trip Report - "Utilization of Titan III Family Launch Vehicles for NASA Logistics - Discussion at Martin/Denver, February 12, 1968, Case 720 by H. S. London dated February 27, 1968.

[5] BIGS = Booster Inertial Guidance System

[6] GIGS = Gemini Inertial Guidance System

2.3.1 Man-Rated Propulsion

The IIIM core liquid engines were described as "uprated versions of the Titan IIIC first stage" and "essentially the same second stage engine--with mods for unique flight-control actuators and redundant and man-rating features". The above two quotes are really "tongue in cheek". In reality a new engine system has been under development since 1965. The engines are scheduled for qual. in mid 1968. Both stage I and II engines will be dynamically stable, will have substantially improved or new components, and redundant wiring. In addition, the first stage engines have improved Isp (6 seconds) and greater thrust (520,000 lbs versus 474,000 lbs) at sea level. After development these engines will be installed in all Titan III launch vehicles.

2.3.2 Other Titan III Man-Rated Systems

As stated previously, only the Titan IIIM is to be "man-rated". However, after the IIIM main propulsion is qualified they will have become standard on all approved Titan vehicles. In addition, the IIIM core will have the man-rated features. The Titan IIIB has the capability of lifting a Gemini 2 man spacecraft to most of the orbits of interest for the orbital workshop study. It was therefore germain to ask Martin as to the nuances and costs of having man-rated lower payload Titan vehicles based on the IIIM vehicle. Possible approaches are:

(1) Use the IIIM core to make a new Titan IIIB,

(2) Man-rate the present IIIB[7] core with IIIM systems,

(3) Man-rate Titan IIID or IIIC birds either using IIIB or IIIM cores. (This would require a man-rated 5-segment SRM system and possibly also the Transtage).

At the time of the memo, Martin indicated they would investigate the area and provide performance data, recommendations and cost. The subject is discussed in a memo by H. S. London[4].

2.4 Bulbous Payloads

Many of the candiate NASA payloads for Titan III vehicles require "bulbous" or hammerhead configurations. Martin presented

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[7]The Titan IIIM core is a lengthened first stage version of the IIIB core.

the available data on the configurations wind tunnel tested and/or analyzed. The results are presented in Figure 11 as based on the following assumptions: (1) annual winds of NASA TN D-610, (2) 93° launch azimuth, 220° wind azimuth, and (3) max trajectory $q\alpha\beta$[8] of 3800 lbs/ft^2. Two limitations were found to exist: (1) a minimum length-to-diameter limit of 1.1 caused by transonic buffeting effects and (2) an overall length limitation caused by impact and wind placards.

The data of Figure 11 although stated to be based on Titan IIID are also valid for the IIIM. However, the data are valid for non-manned safety factors of 1.25 rather than for the usual 1.40 of man-rated systems. In addition, the max $q\alpha\beta$ value of 3800 is probably too high for a man-rated system.

The launch probability values of Figure 11 are based on a yearly launch cycle. If one could limit launch dates to those months having more favorable winds (i.e., omit January, February, and March) the launch probability would be significantly improved. Martin said they would rework Figure 11 to account for acceptable man-rated practice and would present the resulting launch probability data on a reduced period as well as a yearly basis.

2.5 Growth Titan Versions

Martin has studied several growth versions of Titan III vehicles both with and without transtage options. The major concepts of new launch vehicles are the Titan IIIF and Titan IIIG.

The Titan IIIF is a non man-rated Titan IIIM plus transtage. Man-rating redundancy and unnecessary equipment are eliminated. Substantial reductions in unit price of the basic IIIM are possible through the relaxation of man-rating acceptance tests. A IIIF bird can increase equatorial synchronous payload up to 70%[9] over a TIIIC.

The Titan IIIG has a 15 ft. diameter core with a 4 engine first stage, and can use 7-segment 120-inch or 5-segment 156-inch diameter SRM. Low earth orbit payloads up to 100,000 lbs are claimed. Martin has generated a serious sales effort to sell this vehicle in competition to the Saturn derivative intermediate family (e.g., INT-20).

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[8] $\alpha\beta$ is the vector sum of the angles of attack in the pitch and yaw planes.

[9] Requires heavier transtage. With present transtage weight, sync. eq. payload is of the order of 26% greater than Titan IIIC.

It must be iterated that the above Titan III vehicles are not approved at the present time.

2.6 Titan III Launch Facilities

At this point in time only Titan IIIC can be flown from the Eastern Test Range (ETR) and Titan IIIB from the Western Test Range (WTR). At WTR the existing Atlas/Agena launch pad (SLC-4 east)[10] is being converted to use with the Titan IIID and a new pad (SLC-6) is under construction for use of Titan IIIM/MOL launches.

At ETR, the Titan IIIC is launched from the ITL[11] which consists of Launch Complexes 40 and 41. At present only Launch Complex 41 is in use. The complex includes a vertical integration building (VIB), and a solid motor assembly building (SMAB). The VIB is used for receipt and checkout of the core vehicle and has 4 test cells and 3 control centers of which 1 set is operational. The SMAB is used for SRM segment assembly and mating to the core; it has 4 assembly bays. Current contract obligations are to support a launch rate of four per year in a 13-week cycle. It is noteworthy that the Martin ETR crew supporting 4 launches per year is only 80 people. The total IIIC associate contract people approximate twice that number. Thus a total of 240 people are required for 4 Titan IIIC launches per year ($\sim\$7 \times 10^6$ per year).[12]

Martin has examined approaches to increase the launch rate at ETR. For example, a rate of 6 per year is possible by augmenting the crew and providing overtime, 8 per year using two crews, 17-20 launches per year on one launch pad by using two VIB cells, two shifts, overtime and weekends. Using both launch pads and 3 VIB cells, 30-40 launches could be programmed with a 15 day turnaround. Near simultaneous launch (within 2 hours) of two vehicles are then possible. The latter rate is the maximum potential of the current ITL.

For conversion of an ITL pad to IIIM or IIIF usage, Martin recommends an "on-pad" 7-segment motor assembly. Thus the SMAB would be bypassed. This concept results in a straightforward low cost approach of minor mods. These mods are associated with stiffening the transporter, relocating service platforms, raising the height of the (UES) launch pad shelter and structure mods (i.e., concrete) to protect against the larger overpressure generated by the IIIM 7-segment SRM's. A man-rating IIIM type of ground checkout equipment would also be required.

[10] SLC = Space Launch Complex

[11] ITL = Integrate Transfer Launch Facility

[12] Data provided by Martin

At WTR the Titan IIIM (MOL) facility (SLC-6) and the Titan IIID facility (SLC-4E) are designed for on-pad SRM assembly. The design of the IIIM facility has considered up-rating for larger Titan vehicles including the 15 ft. diameter core, 5-segment 156-in. diamater SRM Titan IIIG configuration. Launch capabilities at WTR were not made available at the time of this memo.

C. Bendersky

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Attachments

TABLE 1 Cost Data

See Writer for Copy.

STANDARD AGENA SPACEFRAME

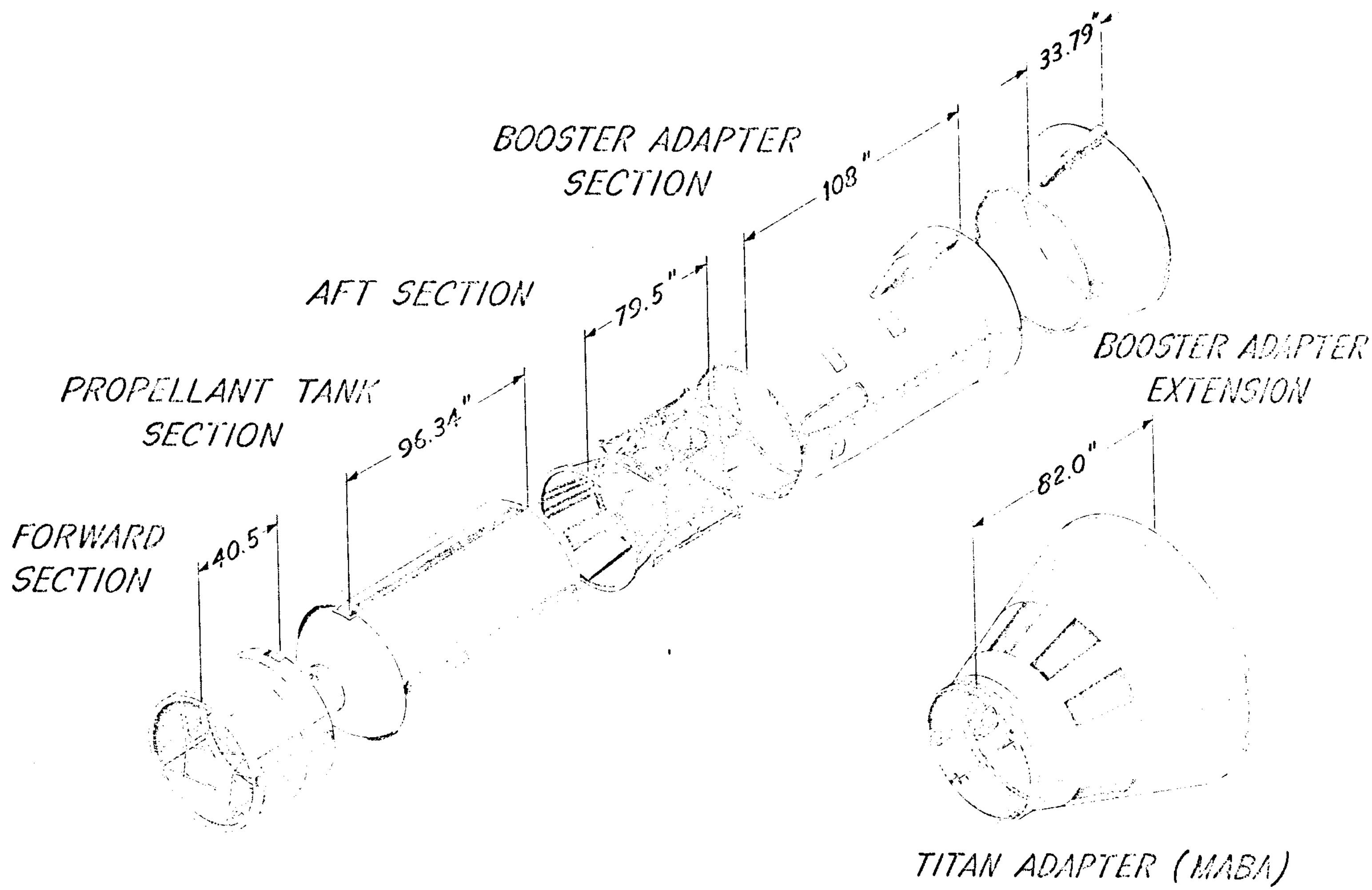


FIGURE 1

SECONDARY PROPULSION SYS, DUAL THRUST LEVEL

- FUEL/OXIDIZER: UDMH/N_2O_4 AND NO
- THRUST LEVELS: 16 & 200 POUNDS
- TOTAL IMPULSE: 40,000 LB-SECS
- IMPULSE RANGE (PER FIRING): 12 TO 10,000 LB-SECS
- MAXIMUM STARTS
  - 200 LB THRUSTER: 20
  - 16 LB THRUSTER: 90

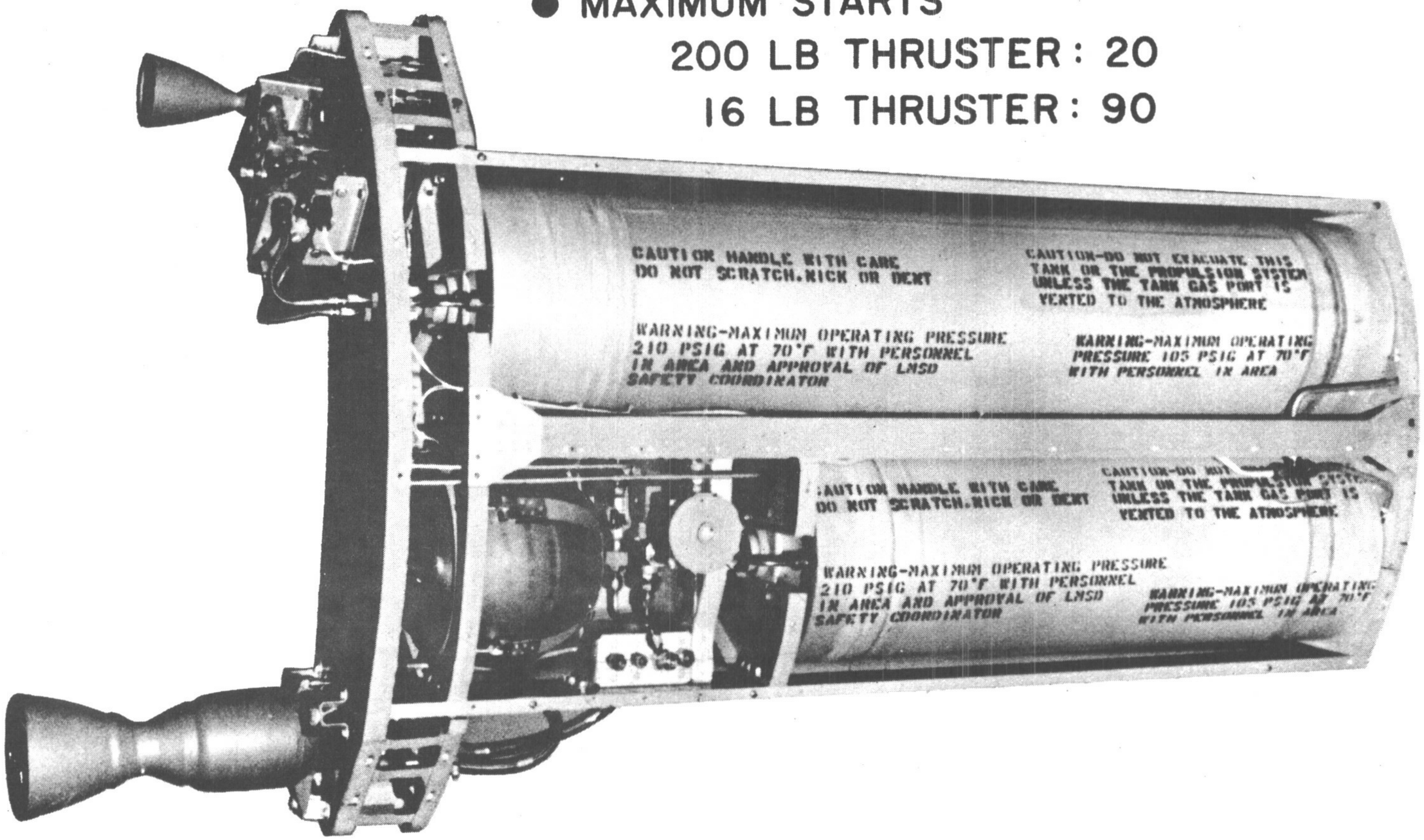
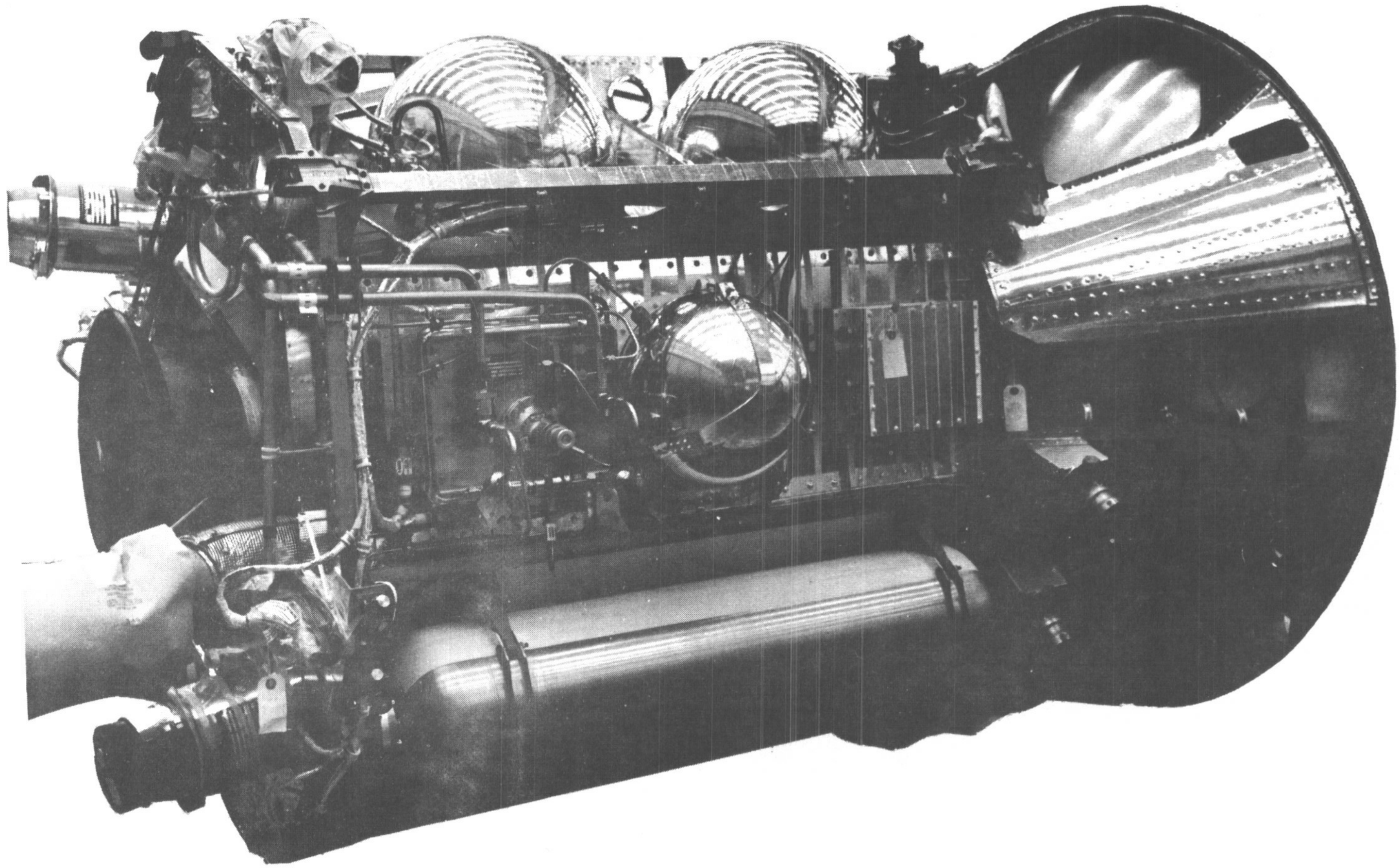


FIGURE 2

SECONDARY PROPULSION SYSTEM



- FUEL/OXIDIZER : HYDRAZINE MIXTURE/ N_2O_4
- THRUST :
- TOTAL IMPULSE : 80,000 LB-SEC
- IMPULSE RANGE : 75 TO 40,000 LB-SEC
- NUMBER OF STARTS : 8 OR MORE

FIGURE 3

IMPROVED AGENA

DEVELOPMENT SCHEDULE

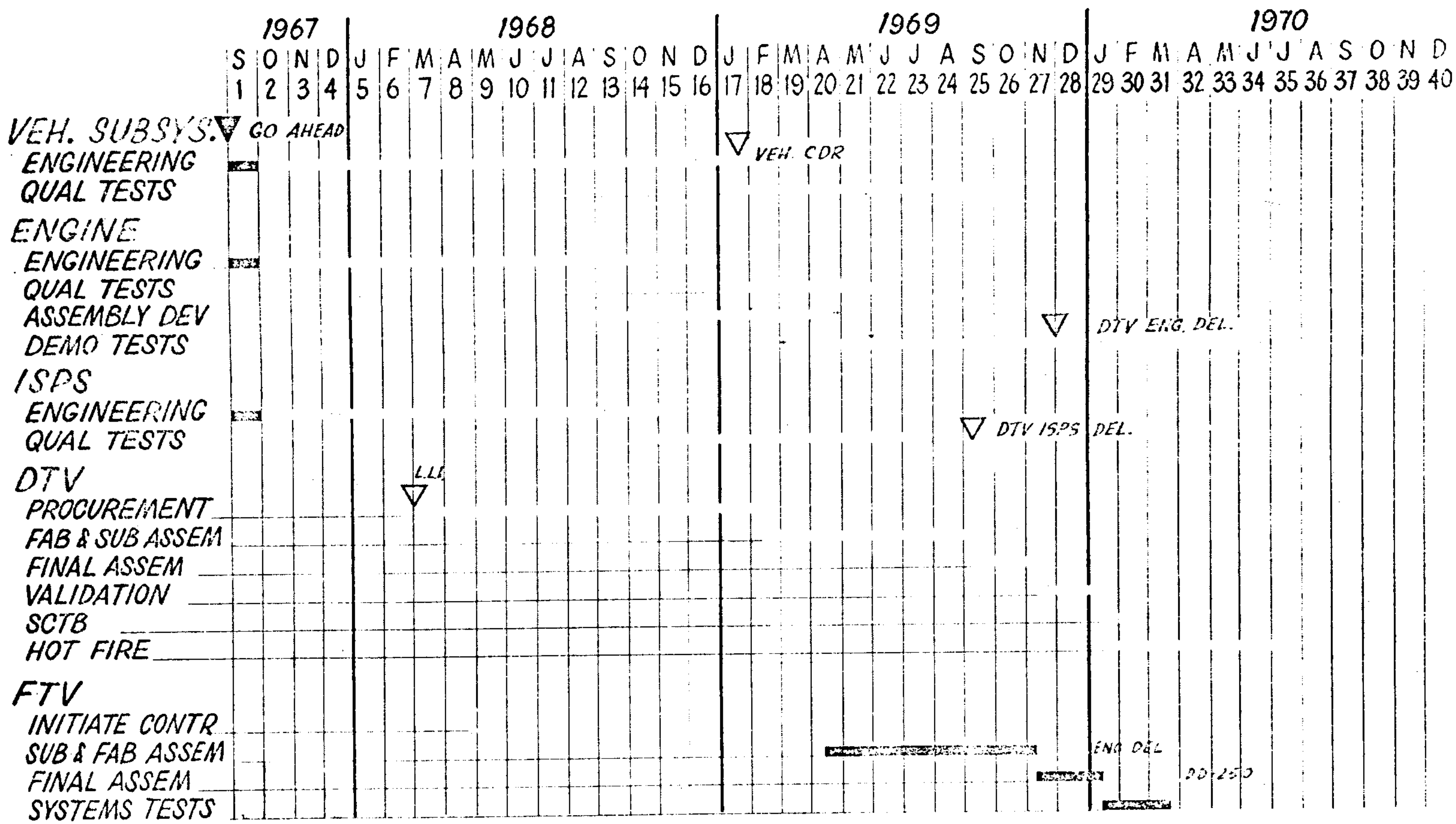
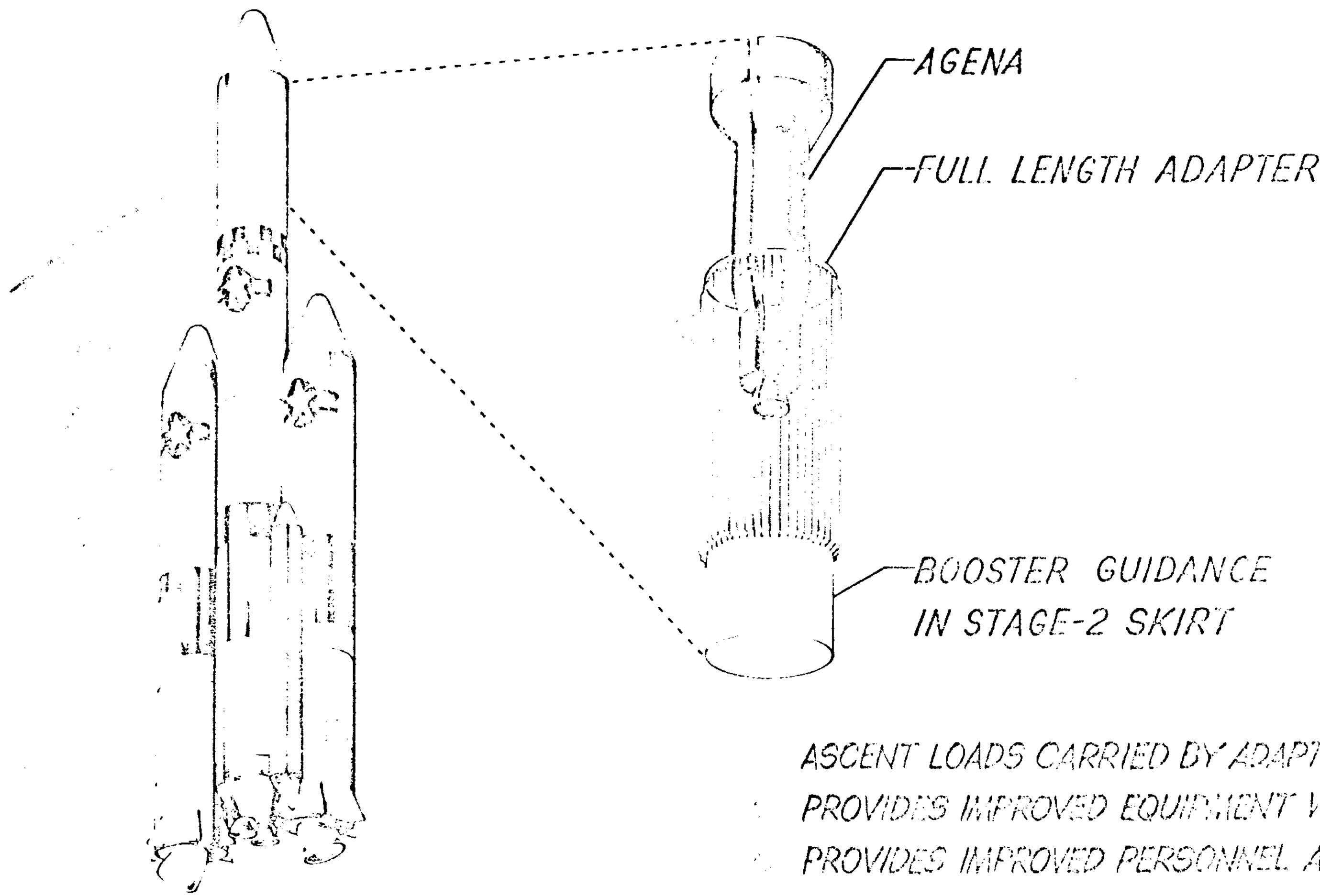


FIGURE 4

TITAN/AGENA FULL-LENGTH ADAPTER



- ASCENT LOADS CARRIED BY ADAPTER
- PROVIDES IMPROVED EQUIPMENT VOLUME
- PROVIDES IMPROVED PERSONNEL ACCESS

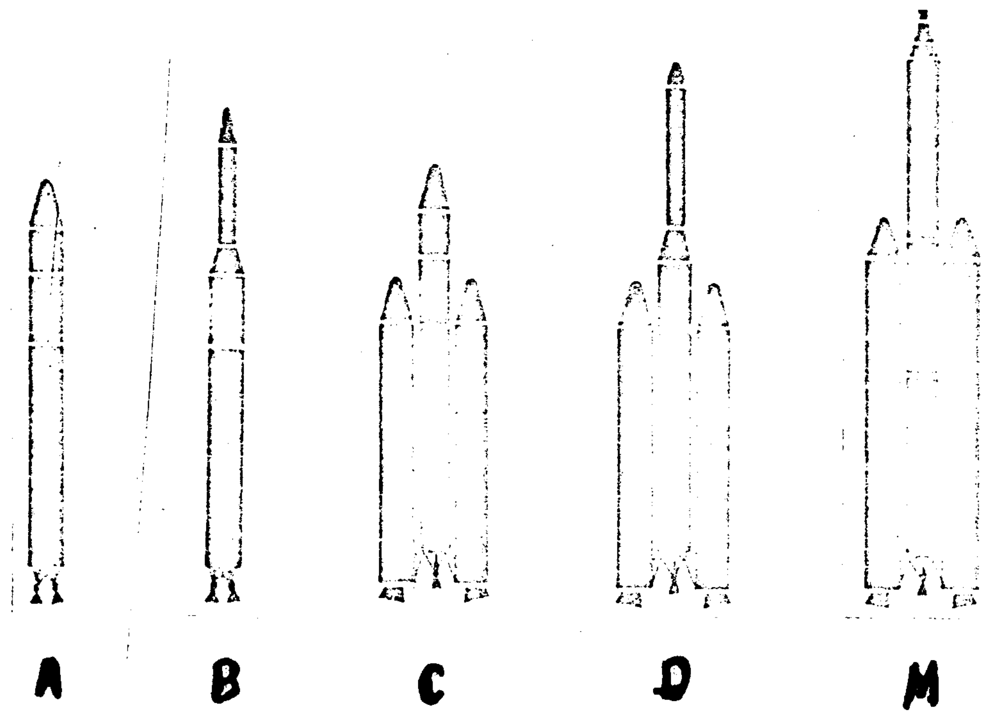
FIGURE 5

LAUNCH FACILITY STATUS

BOOSTER		OPERATIONAL PADS		PROJECTED PADS	
NAME	MODEL NO.	WTR	ETR	WTR	ETR
THORAD	SLV-2G	SLC-1-E/W SLC-3-W	—	SLC-2-E/W	C-17A/B C-12 OR 14
	SENIOR	—	—	SLC-1-E/W SLC-2-E/W SLC-3-W	C-17A/B C-12 OR 14
ATLAS	SLV-3	SLC-3-E SLC-4-E	C-12 C-13	—	—
	SLV-3A	—	—	—	C-13
TITAN IIIB	SLV-5B	SLC-4-W	—	—	C-40/41
TITAN III D/F	SLV-5D	—	—	SLC-4-E SLC-6	C-40/41
	SLV-5F	—	—	SLC-6	C-40/41

FIGURE 6

APPROVED TITAN III CONFIGURATIONS

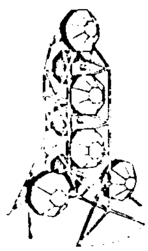
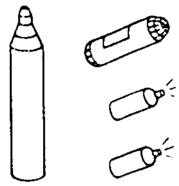
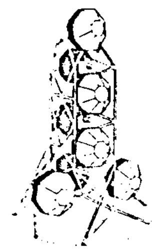
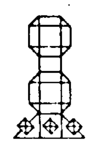
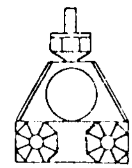


These members of the Titan III family of launch vehicles have flown or are part of a firm development program. Other configurations discussed in this presentation are not officially approved but are under study as a part of the Titan III growth potential.

FIGURE 7

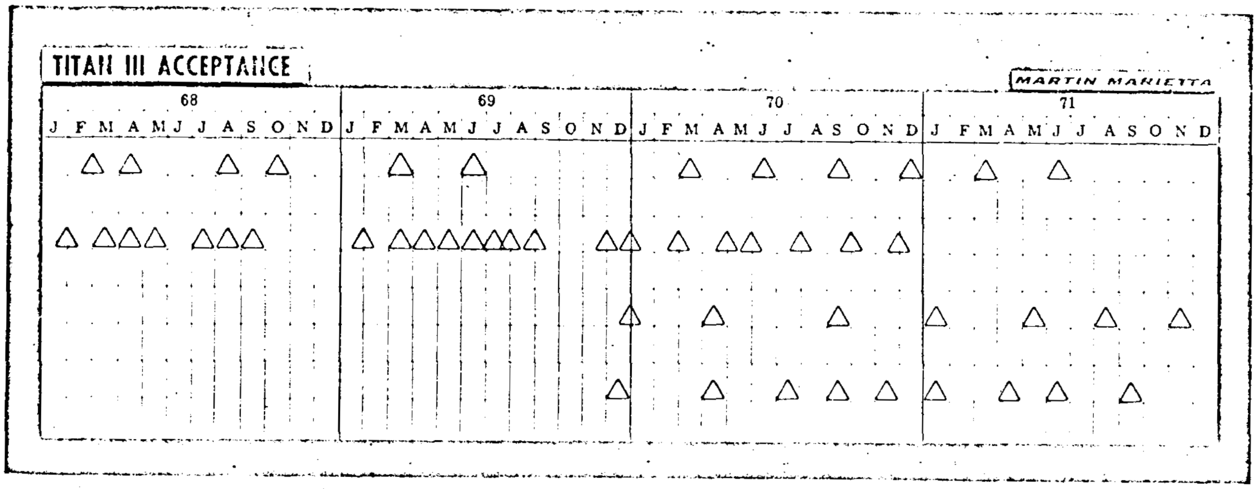
TITAN IIIC FLIGHT TEST SUMMARY (CONCL)

AF

	16 JUN 66	3 NOV 66	18 JAN 67	28 APR 67	1 JUL 67
VEHICLE	C-11	C-9	C-13	C-10	C-14
PAYLOAD DESCRIPTION	 8 COMSATS	 GEMINI B REENTRY MODULE SIM. LAB (26 EXPRS) 3 SATELLITES OV 1-6 OV 4-1T OV 4-1R	 8 COMSATS	 2 VELA SATS 3 ORS 1 SPIN INTERSTAGE	 1 DODGE 1 LES-5 3 572 COMSATS 1 DATS
RESULTS	MISSION ACCOMPLISHED; 18,200 N MI CIRC. ORBIT	GEMINI B WAS RELEASED IN A REENTRY TRAJ. SIMULATING RETURN FROM ORBIT; SATS WERE INJECTED INTO A 160 N MI CIRC. ORBIT	MISSION ACCOMPLISHED; 18,200 N MI CIRC. ORBIT	MISSION ACCOMPLISHED; 4280/62,000 N MI ELLIP. ORBIT	MISSION ACCOMPLISHED; 18,200 N MI CIRC. ORBIT

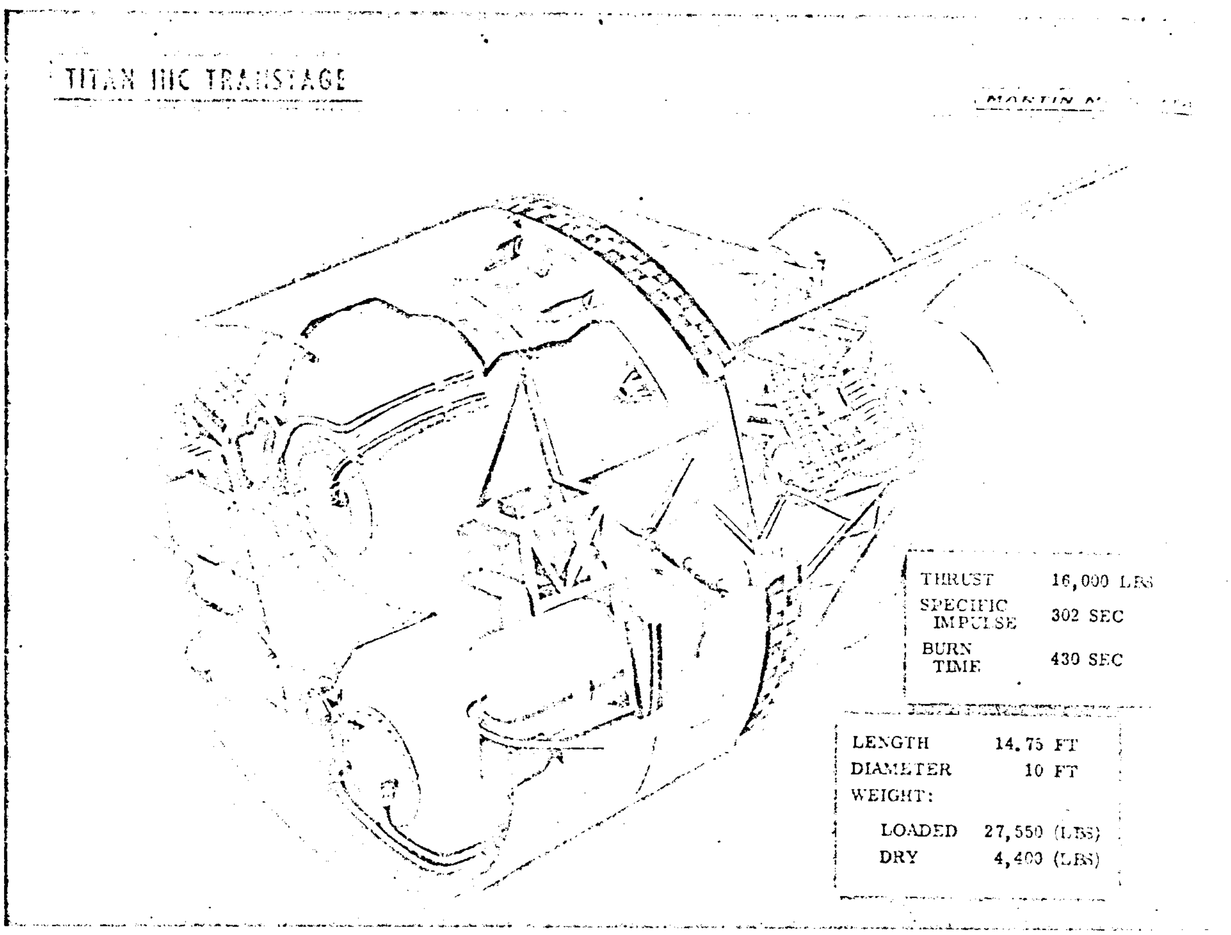
Summary of the five other Titan IIIC flights made to date. Vehicle C-9 orbited a simulated MOL vehicle containing twelve scientific experiments. Data were received from the laboratory for 30 days. The synchronous orbit mission with eight communication satellites as payload is considered the most complex flight sequence demonstrated to date.

FIGURE 8



The current schedule of acceptance of Titan III vehicles by the Air Force. The schedule shows a firm production base over the next four years that will stabilize manufacturing and overhead costs and ensure maintenance of high-quality skills and experience. By 1970 the Titan III production rate is anticipated to be 18 vehicles per year or one every 20 days.

FIGURE 9



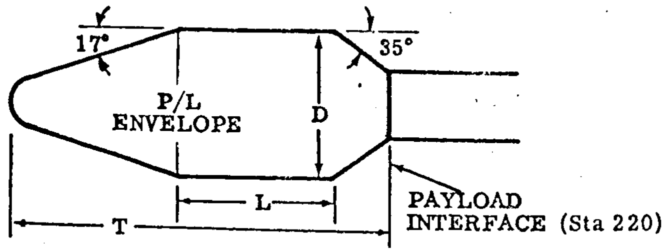
Basic characteristics of the Titan III Transtage. Details of mission flexibility are provided in the presentation on payload capabilities.

This is the improved Transtage configuration to be incorporated in Vehicle 17. The Transtage comprises the propulsion module (aft) and the control module (forward). The propulsion module contains the two 8000-lb thrust engines, propellant tankage, and pressurization systems. The control module contains all the electronics systems and the attitude-control system. Hydraulic power is provided by an electrically driven pump.

FIGURE 10

T-III BULBOUS CAPABILITY WITHOUT TRANSTAGE

MARTIN MARIETTA



DIAMETER (D)	CYLINDRICAL LENGTH (L)	TOTAL LENGTH (T)	LAUNCH PROBABILITY
13 FT	14.5	31 FT	99%
13 FT	23.5 FT	40 FT	99%
15 FT	16.5 FT	38 FT	99%
15 FT	22.5 FT	44 FT	99%
18 FT	20 FT	46 FT	99%
18 FT	24 FT	50 FT	99%
20 FT	22 FT	50 FT	89%
20 FT	24 FT	53 FT	86%

This chart shows launch probability (probability of wind conditions remaining within imposed placard) for various bulbous payload sizes. In the cases where two identical diameters are listed, the first is matched with the minimum allowable cylinder length (L/D = 1.1), and the second is matched with a typical cylindrical length. This analysis was based on the use of the Titan IIID vehicle.

NOTES:
(1) Annual winds of NASA TND-610
(2) 93° launch azimuth, 220° wind azimuth
(3) Max $q\alpha\beta$ = 3800 lbs/ft^2
(4) Valid for Titan 3M

FIGURE 11

BELLCOMM, INC.

Subject: Selected Comments on Agena and Titan III Family Stages
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From: C. Bendersky

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